CHAPTER 1

INTRODUCTION

1.1 Background of Study

Concrete is one of famous construction materials which needs to be improve in terms of strength as it cannot afford to stand alone in order to carry large amount of load. The strength of concrete structure usually can be improve by using internal steel reinforcement bars. However, reinforcement bars will reduced in strength with respect to the time. Therefore, reinforced concrete needs help from external fibre reinforced polymer.

Fibre-reinforced polymer (FRP) is a combination of materials consists of polymers and fibres such as glass, carbon and aramid. FRP is used in the industry especially construction due to high strength to weight ratio, high resistance to corrosion and can be used to upgrade or for maintenance of damage structure. Among all types of FRP, the highest strength and lighter FRP is the one with carbon. This has been proven since it is not only used in construction industry but also in aerospace and automotive industry.

The fibre content and density of carbon are in the acceptable range with average percentage of weight if compared to glass fibre and aramid. However, the longitudinal tensile modulus and tensile strength are the highest than the other two composite materials. Therefore, carbon has been used to retrofit beams in order to improve strength of structures.

TABLE 1. Mechanical properties of different composite materials (Head, 1996)

Materials	Fibre content (% by weight)	Density (kg/m^3)	Longitudinal tensile modulus (GPa)	Tensile Strength (MPa)
Glass fibre/polyester GFRP laminate	50-80	1600-2000	20-55	400-1800
Carbon/epoxy CFRP laminate	65-75	1600-1900	120-250	1200-2250
Aramid/epoxy AFRP laminate	60-70	1050-1250	40-125	1000-1800

In construction industry, FRP contributes a lot because it can improve the strength of the structures. The usage of FRP has been agreed as one of the alternative which is value for money as it can improves the strength of structures (Hollaway & Leeming, 1999). The interaction between concrete and FRP gives huge impact towards the strength of a structure especially in the presence of internal steel reinforcement. Besides that, it is important to design a structure which minimize thermal stress and resist from fatigue. All of these can be achieved by carbon which can overcome fatigue problem and minimal thermal stress.

Steel reinforcement bar is one of the component that can help to hold the concrete while it is in tension. Since concrete is very strong in compression but weak in tension, it is very important to have the reinforcement bars in order to get the balance between both of compression and tension.

Shear capacity usually affected by the force provided by reinforcement. The shear will be transfer through aggregate interlocking or shearing of reinforcement joint. The shear transfer through the reinforcing bar is called as dowel action. Normally the concrete that not undergoes cracking, the shear is transfer through aggregate interlock while the others through dowel action.

1.2 Problem Statement

Concrete is one of important construction material but it is not able to stand alone without the presence of steel reinforcement as the strength is not enough to support bigger loads. Therefore, most of the design will involve the presence of internal steel reinforcement and external fibre reinforced polymer.

Most of the existing structures that have been built years ago have reinforcing steel bars. The bars really give the effect to the strength of the structure. The problem is the condition of the internal reinforcement will be different with respect to the service time. The strength of the structure will continue to become decreases. Therefore, it needs to be overcome in order to maintain the structure.

In addition, the presence of many structures which have been built for years ago and have high historical value needs to be improve in term of strength in order to make sure that those structures will remain there in the future. Unfortunately, over-emphasised preventive maintenance will gives the effect towards the originality of the material used and cost effective. As the materials need to be replace, the originality of the component of that structure will be affected and the cost will also increase because of the new material used.

Besides that, the other solution that has been decided nowadays is to demolish the existing structure and replace with the new structure. This action will gives high impact towards the cost because it needs to be come out with new design, material and construction cost. Furthermore, it will needs lot of time to rebuild the structure.

However, in order to maintain a structure using FRP, it is important to know the right way to apply the external reinforcement. This is because there are two relevant ways to use FRP externally which are by U-jacketing and side-bonded. Both of these methods will give different impacts towards the shear transfer. But the studies regarding U-jacketing is still not enough. With regard of strengthening the existing structure, T-beams have been considered as the applicable shape to be studied. This is because structure consist of beams and slabs. Slabs and beams when connecting to each other will automatically form T- shape. The problem comes when there are lack of researches involving T-beams as compared to rectangular beams.

Fibre Reinforced Polymer (FRP) has been proven to be developed in construction industry. Despite of its ability to be used for multiple purposes, the shear transfer studies between the internal steel stirrups and externally bonded FRP is still limited. Thus, the effectiveness of externally bonded FRP as one of the strengthened member is still questionable. This study will be investigating the interaction between internal stirrups and externally bonded FRP.

1.3 Objectives

Beam is normally subjected to flexural and shear stresses. Most of the time the shear deformation has been ignored especially for a slender member that has several times larger than its depth. But for a smaller span to depth ratio beam, the shear will be more significant. Thus, the following become the objectives of this project:

a) To determine the effect of internal steel stirrups and externally bonded FRP.
b) To determine the effect of shear reinforcement ratio.

1.4 Scope of Study

The experiment will be conducted in Structural Laboratory of Universiti Teknologi PETRONAS. The result will be evaluated upon the loading that can be supported by T-beam with different characteristics of shear strengthening members. This study will be focused on the experimental work in order to determine the effect of width and spacing ratio between FRP applied to the T-beam. Besides that, shear reinforcement ratio which is between internal steel reinforcement and external applied FRP also will be determined. The time taken to evaluate the result would be about 28 weeks.

1.5 Significance of Study

FRP is one of the best alternative to maintain and repair structures as it is an efficient and cost friendly method to upgrade the capacity of RC beams. In terms of flexure, FRP has been trusted to be a part of RC design. However, there is no official approval to use FRP as the shear strengthened members due to large parameters that need to be studied further. Hence, this paper covers two of the main parameters.

CHAPTER 2

LITERATURE REVIEW

2. FIBER-REINFORCED POLYMER (FRP)

2.1 Introduction to FRP

Fiber-reinforced polymer (FRP) is a type of composite material consist of polymer and fiber which act linearly in tension up until failure which is different with other components such as steel and concrete (Bousselham & Chaallal, 2004). FRP has becoming one of the famous components to be used in construction industry to increase the strength of reinforced concrete Khalifa, Gold, Nanni, and MI (1998). The use of FRP to repair and rehabilitation of infrastructure has becomes a broad topic since it has been used for more than decade ago (Meier, 1995). FRP has many advantages as the composition of polymer and fiber is very ideal.

Properties of FRP and the materials used in FRP has been discussed in one of the important code which is ACI 440R-96 (Taha & Shrive, 2003). Moreover, FRP can recover serviceability limit when it is used to retrofit the beams or slabs (Czaderski & Motavalli, 2004). It can be used as a method to increase the strength of existing structure which has been built for years ago as it can be applied externally. Reinforced concrete beam can be recovered using FRP to increase service loads and have been widely established especially on bridges (Teng, Chen, Smith, & Lam, 2002).

Although this may be true there are still uncertain understanding on performance of FRP strengthen beams. One of the parameter that is still questionable is the interaction between internal steel stirrups and externally bonded FRP (Mofidi & Chaallal, 2014a). External FRP can be applied in three ways which are through full wrapping, U-wrap or side-bonding. The performance of beams retrofitted with FRP is different due to the configuration of FRP applied (Grande, Imbimbo, & Rasulo, 2009). Since full wrappingis difficult to be used for the existing structure, U-wrap or side-bonding has been used frequently. Through many experimental results, many side-bonded beams fails through separation of FRP from concrete while U-jacketing applied FRP fails due to break of FRP and debonding (Lu, Chen, Ye, Teng, & Rotter, 2009).

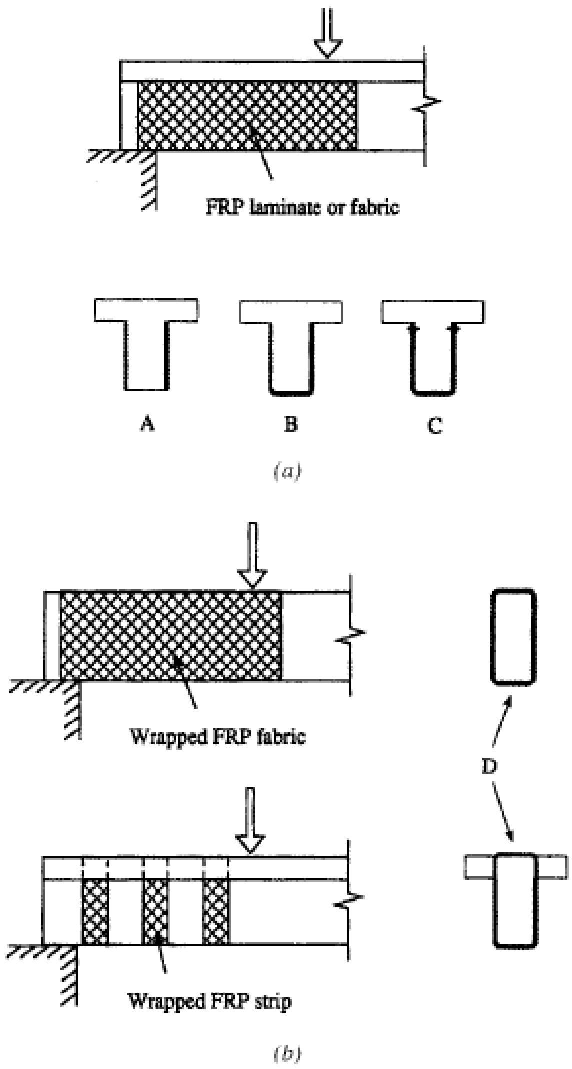

FIGURE 1. Strengthening configuration of external FRP (Triantafillou, 1998).

In addition, strength of beams with applied FRP can be affected by the width of FRP used. Based on study done by Teng et al. (2002) it has been experimentally shown that beam with wide external FRP is the one with higher strength compared with small width FRP. However in terms of layers, FRP cannot be applied in few layers since the beams will have decline in ductility. Increasing the layers of FRP will not give any effect towards shear ability of beams (Bousselham & Chaallal, 2008).

Besides that, spacing of external FRP also plays an important role to the strength of beams. FRP should not be applied in wide spacing in order to have complete diagonal crack without interrupting the external reinforcement (Khalifa & Nanni, 2000). Due to the increases of FRP spacing, post-cracking stiffness will be reduce because of the ineffectual beam captivity (Panchacharam & Belarbi, 2002).

2.1.1 Failure modes in FRP strengthened members

Main failure of beams reinforced by FRP are through the rupture and debonding which caused the FRP in non-uniform ultimate limit state (Lu et al., 2009). Failure modes of FRP strengthened in reinforced concrete structures can be divided into seven main groups which are:

1. flexural failure due to rupture of FRP;
2. flexural failure due to crushing of compressive concrete;
3. critical diagonal crack debonding (CDC) due to shear failure;
4. separation of concrete cover;
5. plate-end interfacial debonding;
6. intermediate flexural crack caused interfacial debonding; and,
7. intermediate flexural shear-crack caused interfacial debonding (IC).

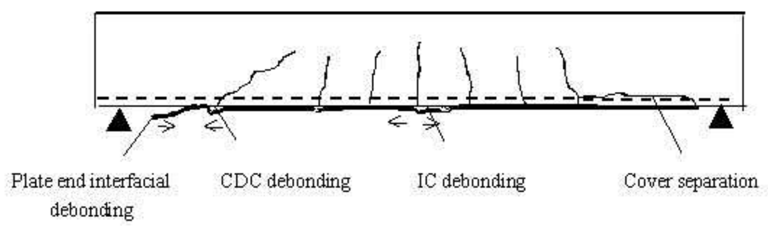

FIGURE 2. Failure modes in FRP

FIGURE 3. Diagonal shear crack (Mofidi & Chaallal, 2014b)

FIGURE 4. FRP sheet debonding followed by diagonal shear failure (Mofidi & Chaallal, 2014b)

FIGURE 5. FRP strips debonding followed by diagonal shear failure (Mofidi & Chaallal, 2014b)

When the beams strengthened with external FRP were tested under higher loading, there are three stages of failure.(Bousselham & Chaallal, 2008). The failure will start with the sign of flexural failure followed by diagonal cracks and then total failure will occur.

As for separation of concrete cover and plate-end interfacial of debonding is called as plate-end (PE) debonding failures. Besides that, intermediate flexural crack and intermediate flexural shear are known as mid-span debonding. The yielding of steel reinforcement caused flexural failure when the ratio of internal steel and FRP reinforcement is very low. This will be followed by tensile rupture of FRP prior to the crush of the concrete. While crushing of concrete occurs due to compression flexural failure before the steel undergoes yielding and comes to FRP failure in the present of higher reinforcement ratio.

According to Abdelhak Bousselham and Omar Chaallal (2008), shear failure will caused by crushing of concrete which is due to low concrete strength of the specimens. Both of debonding and tearing off concrete cover has been categorised as premature failure (Maalej & Bian, 2001). Shear failure also can occur due to concrete which may be due to low strength of concrete. Concrete give high impact towards the bond of the beams which is premature debonding (Deniaud & Cheng, 2004).

FRP rupture usually occurs with slanting shear line that can be seen. Crack starts from the area near the support before moving close to the loading. Sometimes diagonal crack can be seen suddenly (Teng et al., 2002). In addition, there is also shear failure without FRP rupture which occurs without FRP fall into pieces.

Based on previous research, most of the failure of beams retrofitted by U-jacketing failed due to rupture. On the other hand, debonding is also one of the potential failure of the U-jacketing. Not only for U-jacketing, side-bonding faced the problem. Beam will take short time to fail when FRP was pull out (Chen & Teng, 2003). But the situation which FRP peel off is difficult to be seen.

Due to Chen and Teng (2003), spacing of FRP must be closed. In one of code that is use for design stated that internal steel reinforcement needs to be in the range of 0.75d and 300 mm but it is sometimes not applicable since it can be changed due to effectiveness. The effectiveness can be seen if the steel can prevent from crack. However, it is different with FRP. In contrast, the other code which is from UK Concrete Society, it is stated that internal reinforcement must be in the range of 0.8d and W_{frp} + d/4 (Arya, Clarke, Kay, & O'Regan, 2002).

2.2 STEEL REINFORCEMENT

Reinforcing steel bars are a part of the construction materials. Reinforcing bars (rebars) can be divided by two which are smooth and deformed. Besides that, reinforcing bars can be categorised based on the sizes and type which are plain, square twisted, hot rolled, ribbed and cold worked and others.

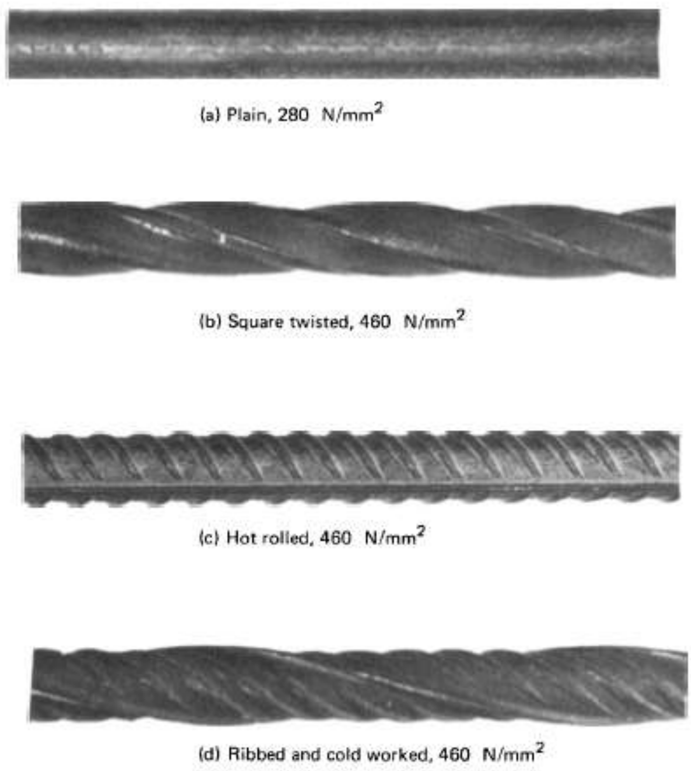

FIGURE 6. Reinforcement types and yield strengths for 16 mm diameter bars (Tilly, 1979)

Used of additional transverse steels in the beam to support the shear caused less influence of FRP towards shear resistance (Bousselham & Chaallal, 2008). It shows that steel has greater shear strength. Modern code nowadays consider concrete and steel as reinforced concrete (RC) members and the shear resistance of RC is the total of concrete and shear resistance (Bousselham & Chaallal, 2004). Therefore, steel is very important in the construction industry to overcome the shear failure of the structures.

2.3 BOND BEHAVIOUR

Many factors influence the bond characteristic of FRP and RC members (adapted from ACI Committee 440 on Bond of Externally Bonded FRP, 2008) which are:

a) Tensile strength of concrete;

b) Shear stiffness;

c) Bond length of FRP;

d) Size and scale size of specimens;

e) Section geometry of specimens;

f) Loading of specimen such as applied shear-to-moment ratio, constant applied moment or moment gradient, Static or dynamic loading and fatigue of specimens

g) Retrofit geometry of FRP;

h) Environmental and Mechanical Exposure;

i) Mixed mode nature of debonding phenomena

In order to achieve the objective of this project it will cover only factor (f) which is due to the loading of the specimens. Bonding between FRP and beams will be affected by the potential of FRP to transfer stresses to that beams. This will cause by width of FRP to width of beam or the spacing. Since concrete has less strength due to tension cause to be necessary for steel reinforcement to be used to support it. Steel reinforcement ratio gives gigantic impact towards the shear resistance of RC beams (Joint ACI-ASCE Committee 445 1998; CEN 1991).

The used of FRP for repairing structural damages is emerging as efficient and effective practice for returning and improvement of the strength of RC members. Most of the approved and trusted method used lately is for members strengthened in flexure. However, it is lack of research studied on the ratio of width and spacing between applied FRP to the T-beam and shear reinforcement ratio which is between internal reinforcement and external FRP.

CHAPTER 3

METHODOLOGY

3. Project Flow

This project consist of four main stages which are literature review, conducting experiments, data collection and conclusion. In literature review it involves preliminary research and understanding on shear strengthening of Reinforced Concrete T-beams. Besides that, this project includes conducting the experiment. During this stage the required experiment will be designed follows by preparing the equipment and materials for that experiment. Based on the experiment, data will be collected and analysed before it comes into the conclusion and report writing.

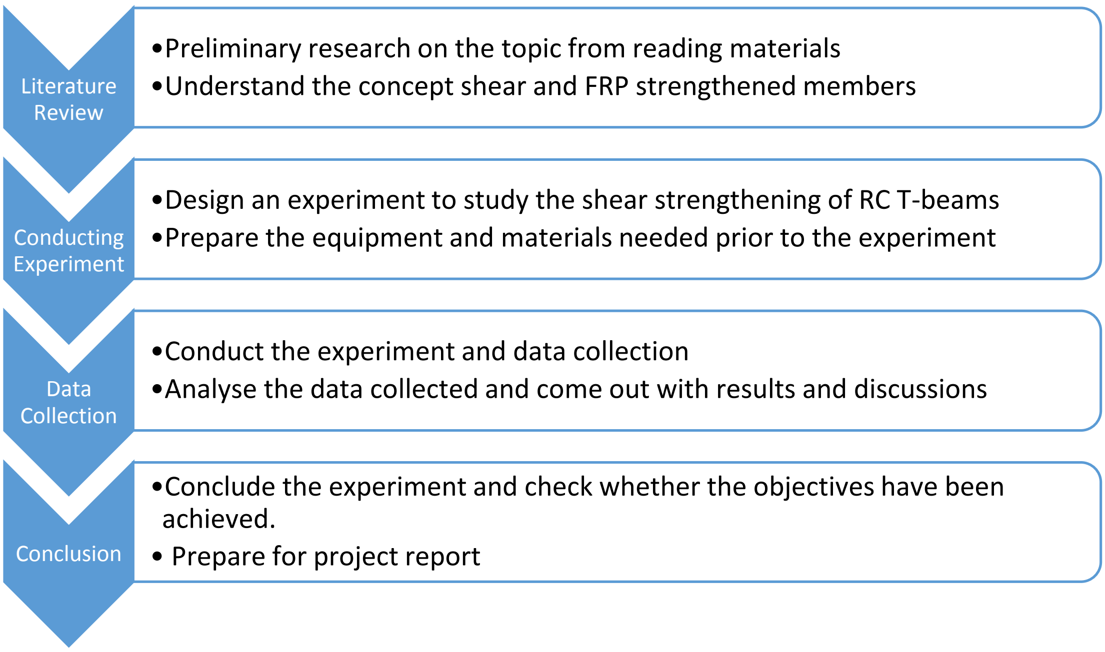

FIGURE 7. Project Flowchart

3.1 Experimental Program

Description of specimens

This experimental studies involved ten tests performed on ten RC T-beams. The T-beams were 2000 mm long and dimensions of T- section are 310 × 260 mm. All the 10 beams will be design as U-wrap or side-bonded Fiber-Reinforced Polymer. In this study, there will be two categories of specimens which are with and without stirrups. The width of the web is 110 mm while thickness of flange is 60 mm. Steel reinforcement consists of four 16 mm steel bars laid in two layers at the bottom and four of 10 mm bars laid at the top as a single layer. The bottom bars attached at the support with hooks to prevent premature attachment failure. Internal steel stirrups of every beams are 10 mm in diameter. The FRP will be applied to T-beam with the help of two components epoxy resin act as glue. Cemented surface will be removed before applying the FRP.

TABLE 2. Description of specimens

	W_f/S_f	U- wrap	a/d
Without Stirrup	Control 1 (T S0)	√	3.11
	100/100 (T S0- CON /Beam 3)	√	3.11
	50/100 (T S0-0.5 / Beam 4)	√	3.11
	50/200 (T S0-0.25 (2) / Beam 5)	√	3.11
	25/100 (T S0-0.25 (1) / Beam 6)	√	3.11

Stirrups, S = 200 mm c/c	Control 2 (TS)	√	3.11
	100/100 (TS- CON / Beam 7)	√	3.11
	50/100 (TS-0.5 / Beam 8)	√	3.11
	50/200 (TS-0.25 (2) / Beam 9)	√	3.11
	25/100 (TS- 0.25 (1) / Beam 10)	√	3.11

Table 2 above shows all the characteristics of the specimens. There are five beams with stirrups and five beams without stirrups. Beams that has no stirrup has been labelled as T S0 while all of beams with stirrups are labelled as TS. As for the control beams of both categories, FRP are not applied on them. In both of these categories, there are five differences between each beams. The continuous U-wrap beams known as T S0-CON or TS-CON. In order to check for the effectiveness of FRP, the width and spacing between FRP has been used differently. The width that are used are 50 mm and 25 mm while the spacing between FRP are 100 mm and 200 mm. For beams with 50 mm FRP and the 100 mm distance between FRP, it is called as 0.5. As for beams with 50 mm with 200 mm spacing FRP are known as 0.25 (2) while 25 mm beams with 100 mm spacing between the FRP are known as 0.25 (1).

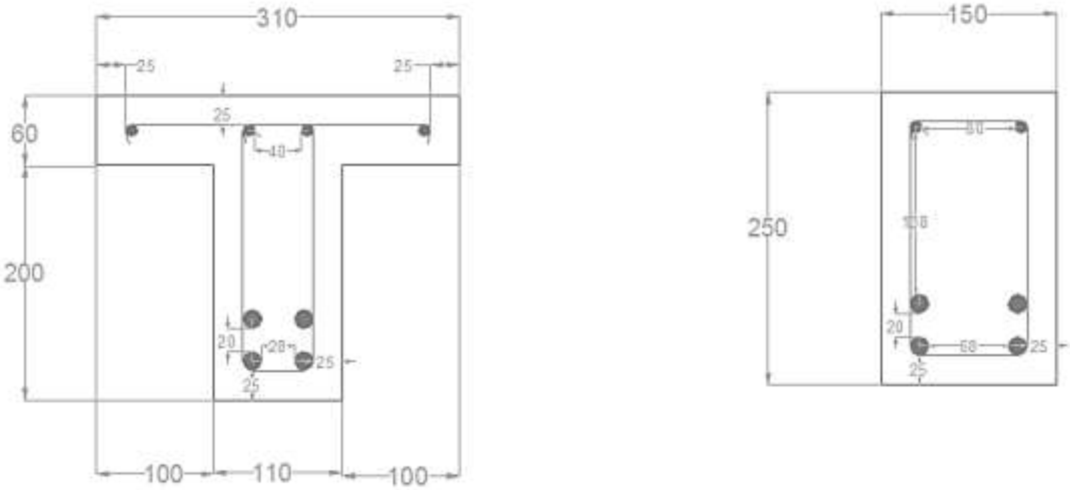

FIGURE 8. Design cross section of RC beams

All of beams that are used in this experimental programme has been ensured to follow this standard size as the above diagram. This is very important in order to have good result and for comparison to be made. Besides that, the position of FRP and steel stirrups of each beams are set up as in figures below:

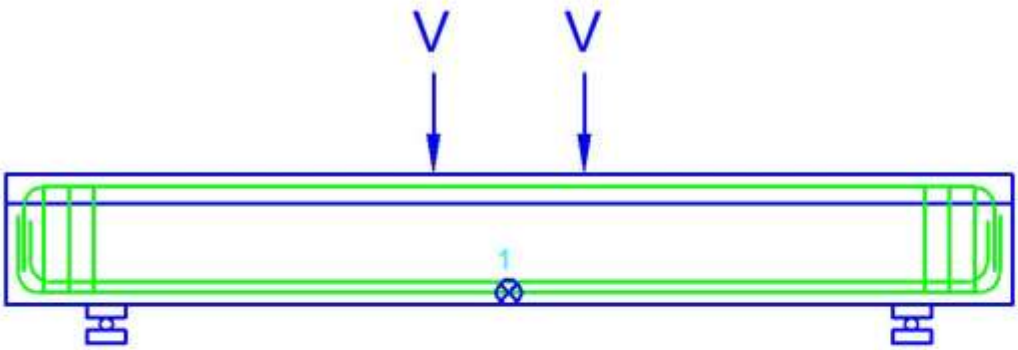

FIGURE 9. TS0

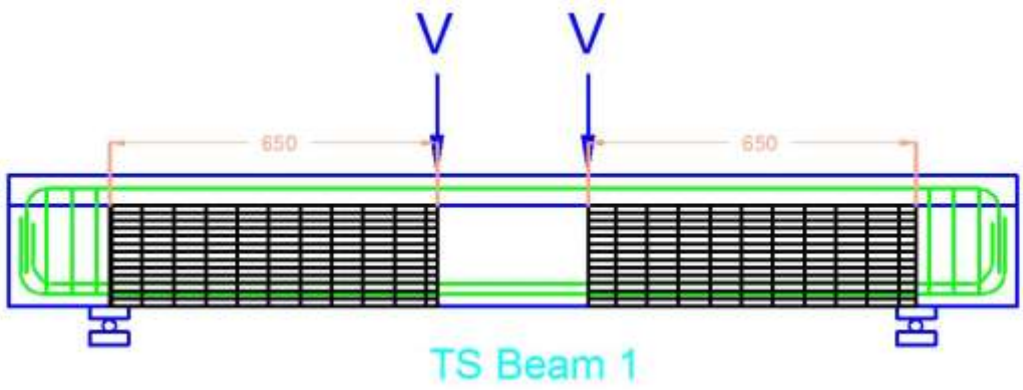

FIGURE 10. TS0- CON

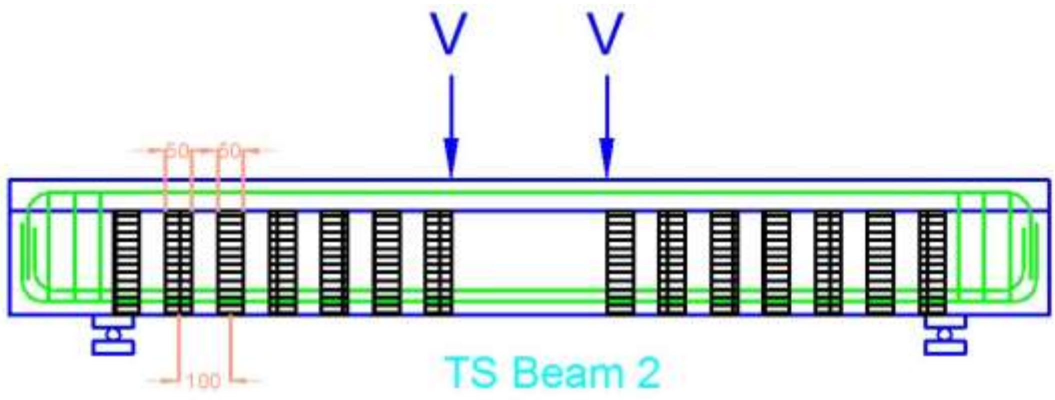

FIGURE 11. TS0- 0.5

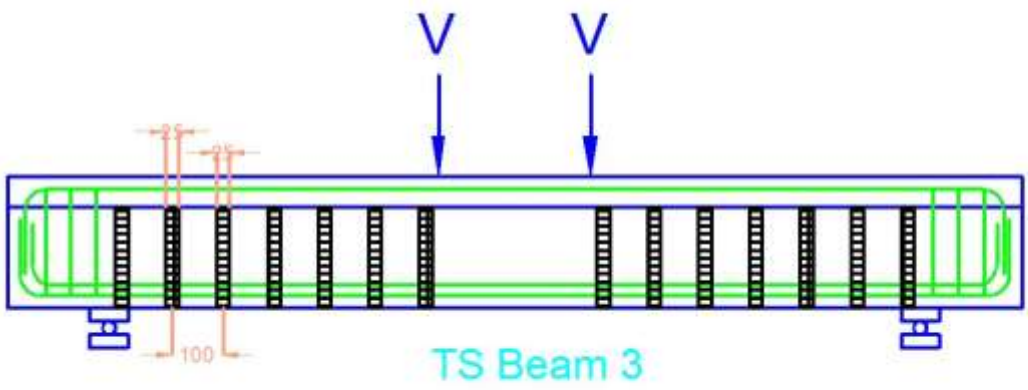

FIGURE 12. TS0- 0.25 (1)

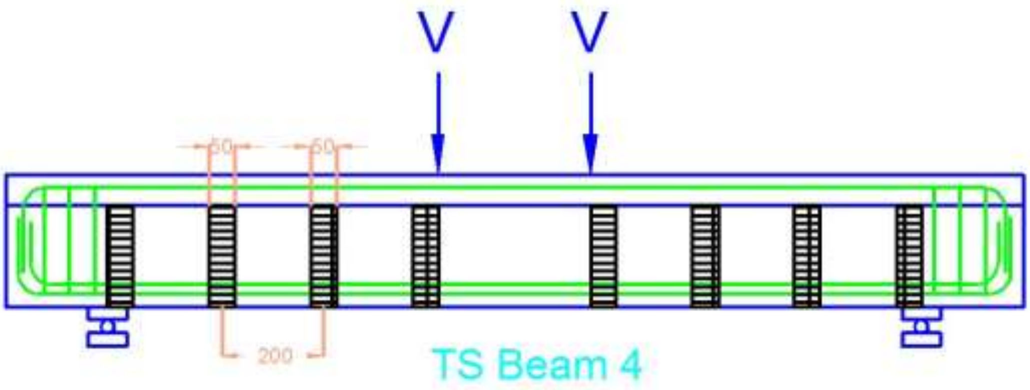

FIGURE 13. TS0- 0.5 (2)

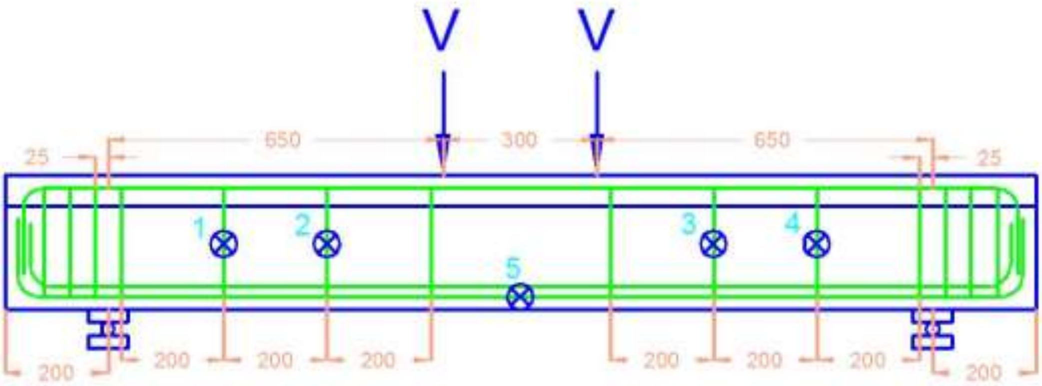

FIGURE 14. TS

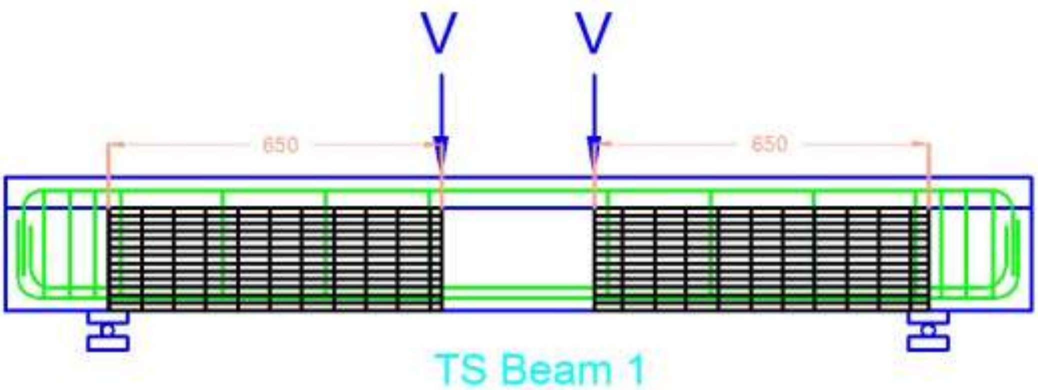

FIGURE 15. TS- CON

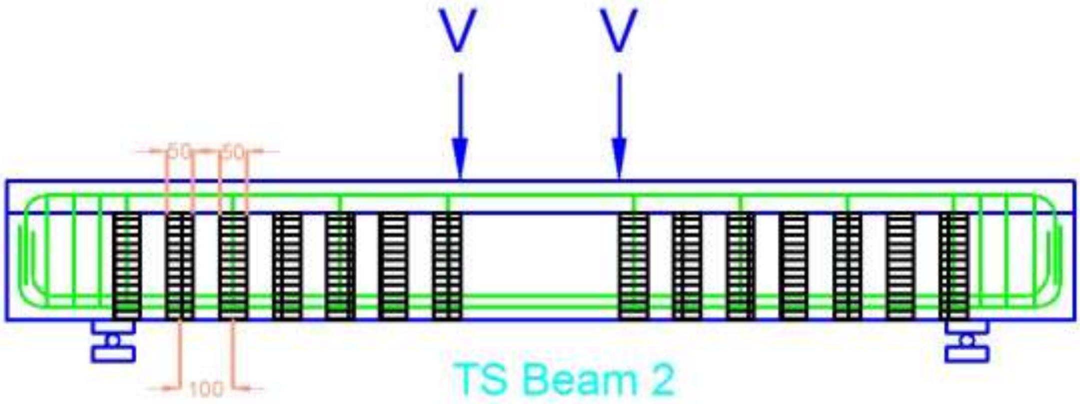

FIGURE 16. TS- 0.5

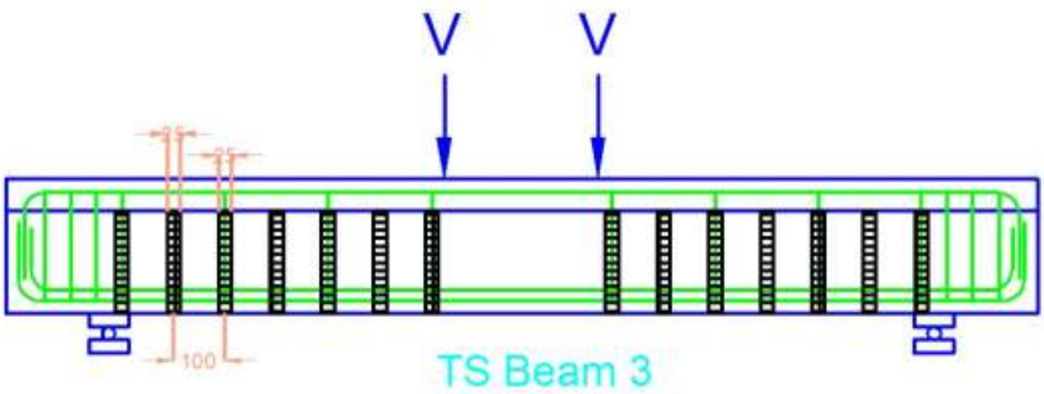

FIGURE 17. TS- 0.25 (1)

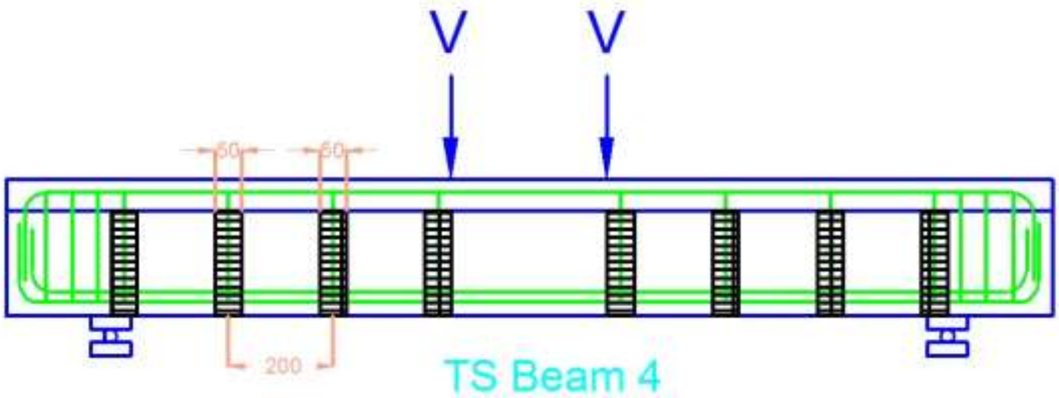

FIGURE 18. TS- 0.25 (2)

3.2 Materials and Methods

A commercially available concrete delivered to the University Teknologi PETRONAS's structural laboratory by a local supplier will be used in this project. In order to take into account for the purpose of this project, T-beams will be designed over- reinforced for shear. Assuming that the beams will not yield. The specimens are predicted to be very bad under the mode of shear compared to flexure. FRP are used as the strengthening material for this study. In the design of strengthening, two methods will be used which are U- jacketing and sides wrapping. Besides that, T-beam will be strengthened by FRP which are different in spacing and width. The test in beams will be on the shear tests, vertical load will be applied using testing hydraulic actuator. The deformation of FRP and transverse steel will be observed in all the specimens. Then, the comparison between all the specimens will be made.

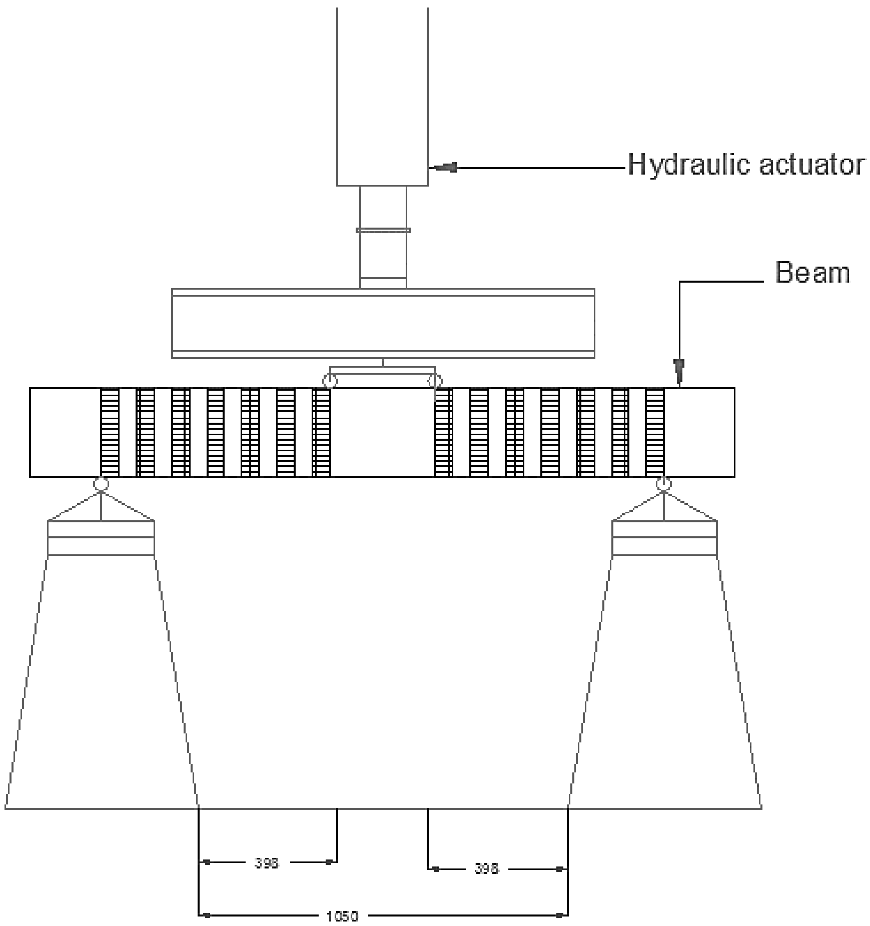

FIGURE 19. Side view of loading configuration

3.3 Process Flow of Experiment

This experiment is started with the preparation of formwork and reinforcement bars based on the proposed dimension for this project. Grade 35 concrete was used for this T-beams during the making of specimens. Harden concrete were set for curing which is the process of protecting moisture loss and kept under acceptable temperature. After that, it will follows by the grinding process which will be required before applying Fibre-Reinforced Polymer to be bonded externally. Then, all the specimens will be tested using hydraulic actuator. Based on the experimental program, the result of all the specimens will be analysed and recorded in a report.

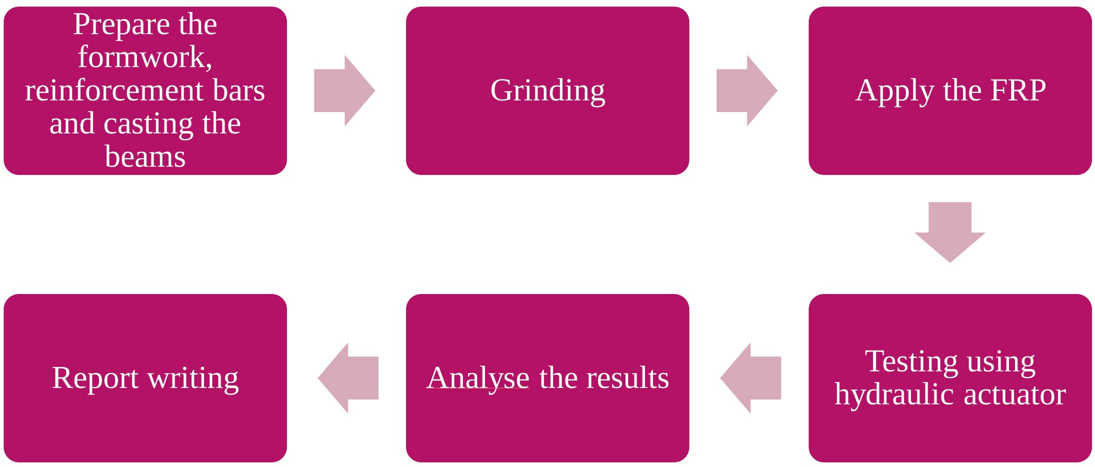

FIGURE 20. Process flow of experiment

FIGURE 21. Preparation of formwork

FIGURE 22. Testing using Hydraulic Actuator

3.4 Key Milestone

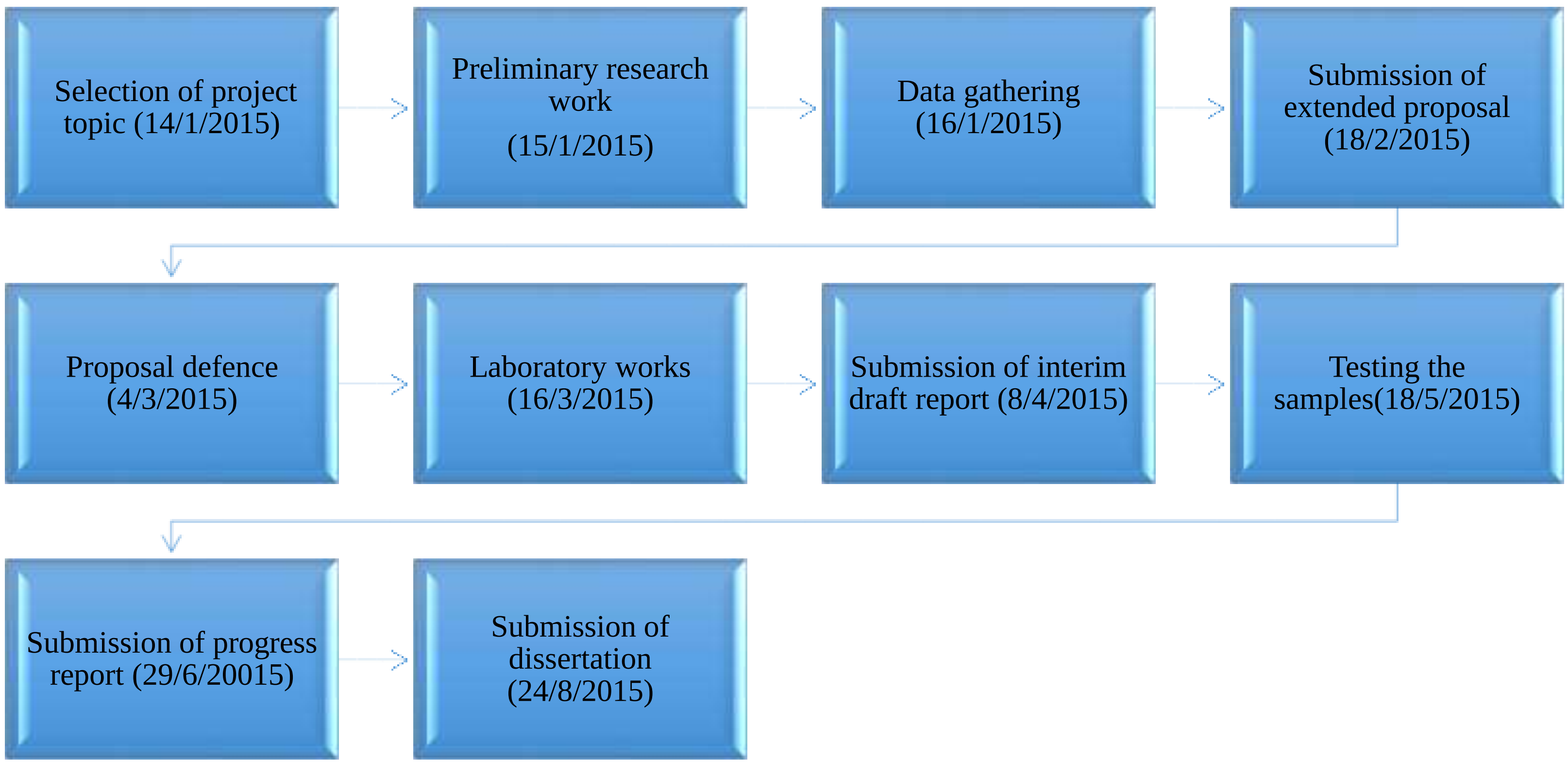

FIGURE 23. Key Milestone

3.5 Gantt Chart

TABLE 3. Gantt Chart

Description	Planning (Weekly)																											
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Selection of project topic	■	■																										
Project topic confirmation			■																									
Identify problems			■	■	■																							
Collecting data			■	■	■	■																						
Discussion with supervisor		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Submission of extended proposal						■																						
Proposal defence								■	■																			
Laboratory works										■	■	■																
Submission of interim report														■														
Result and final findings															■	■	■	■	■	■	■							
Final report preparation																						■	■	■	■	■		
Pre-SEDEX																								■				
Viva																											■	
Submission of final report																												■

CHAPTER 4

RESULT AND DISCUSSION

This chapter discusses the results obtained from the laboratory works. The failure of beams with different shear reinforcement ratio and in the presence and absence of stirrups have been observed. There were 10 T-beams with size 2000 mm long and dimensions of T- section are 310 × 260 mm were cast.

In this study, there were only a test has been conducted in order to identify the effect of internal steel stirrups and externally bonded FRP as well as effect of shear reinforcement ratio.

The effect of shear towards these T-beams have been assessed. The correlation between the presence of stirrups and shear reinforcement ratio with the strength also have been identified.

Strength of Specimens and Percentage Gain

The shear strength of all the specimens and type of failure are obtained in the experiment. Beam TS0 and TS are unstrengthen beams and failed under load of 83.57 kN and 146.44 kN respectively. For TS0 it represents the strength of concrete while TS shows the strength of concrete and steel stirrups which are considered as control beams for this experiment. By comparing these two specimens, it is clearly shows that beam with stirrups are much better than without stirrups. This is because even though steel stirrups have less elastic strain limit, it still has higher ductility (Lu et al., 2009).

FIGURE 24. Crack patterns of the specimens

TABLE 4. Experimental results

Specimen		Wf	Sf	Wf/Sf	Vu,exp (kN)	Vc+Vs (kN)	Vfrp	Percentge gain due to CFRP (%)
With Stirrups	TS	N/A	N/A	N/A	146.441	146.441	0	0.00
	TS - 0.25 (1)	25	100	0.25	122.451	146.441	-23.990	-16.38
	TS - 0.25 (2)	50	200	0.25	147.141	146.441	0.700	0.48
	TS -0.5	50	100	0.50	166.633	146.441	20.192	13.79
	TS - CON	100	100	1.00	131.447	146.441	-14.994	-10.24
Without Stirrups	TS0	N/A	N/A	N/A	83.567	83.567	0	0.00
	TS0 - 0.25 (1)	25	100	0.25	100.260	83.567	16.693	19.98
	TS0 - 0.25 (2)	50	200	0.25	97.761	83.567	14.194	16.99
	TS0 -0.5	50	100	0.50	110.056	83.567	26.489	31.70
	TS0 - CON	100	100	1.00	130.948	83.567	47.381	56.70

Based on the table above, it shows that beams without FRP have higher percentage gain due to Carbon Fiber-Reinforced Polymer (CFRP). This is because FRP contributes more in the absence of internal steel stirrups. Steel stirrups will be more resist towards shear than externally bonded FRP which will cause less contribution of FRP (Bousselham & Chaallal, 2008). For two of the beams with stirrups which are TS-0.5 and TS-CON show the loss in strength because both of the beams has fall before the testing. This may be accidently affected the strength of specimens. Besides that, due to this experimental result, continuous wrap of U-jacketing FRP for beam without stirrups gain a lot of strength in the presence of FRP which is 56.7 percent.

<u>Deflection</u>

Deflection of the specimens with respect to the applied load are very important to be determined. In this study, Hydraulic Actuator has been used in order to make sure that the load were applied consistently until the failure. The results have been separated into two which is in the presence of stirrups and without stirrups. From the experimental results, it can be summarised by using graphs below which represents the strain gauge at the transverse steel.

Without stirrup

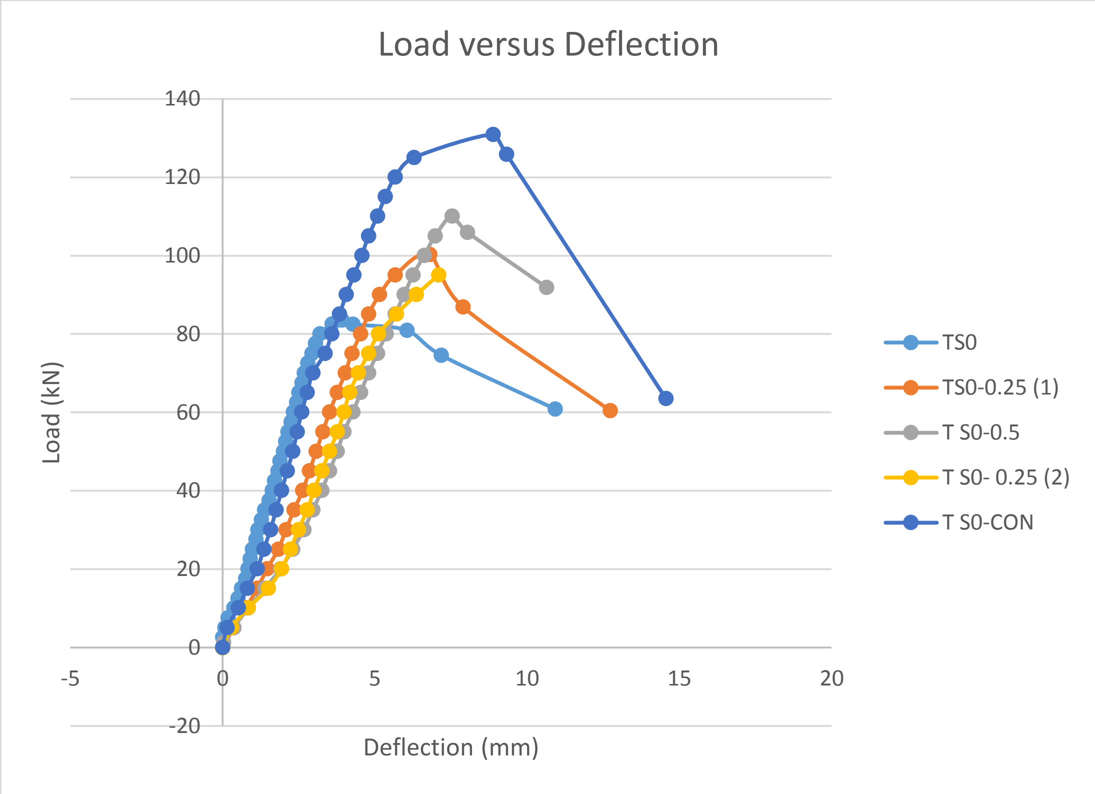

FIGURE 25. Load versus Deflection for beams without stirrups

Under the increasing load, it shows that wf/sf = 1 his higher strength. This can be proved due to deflection at 5 mm. T S0-CON which is the continuous wrap of FRP afford to have higher load during that length of deflection. While it follows with T S0-0.25 (1), TS0, T S0-0.25 (2) and T S0-0.5. This shows the effectiveness of FRP and the role of shear reinforcement ratio.

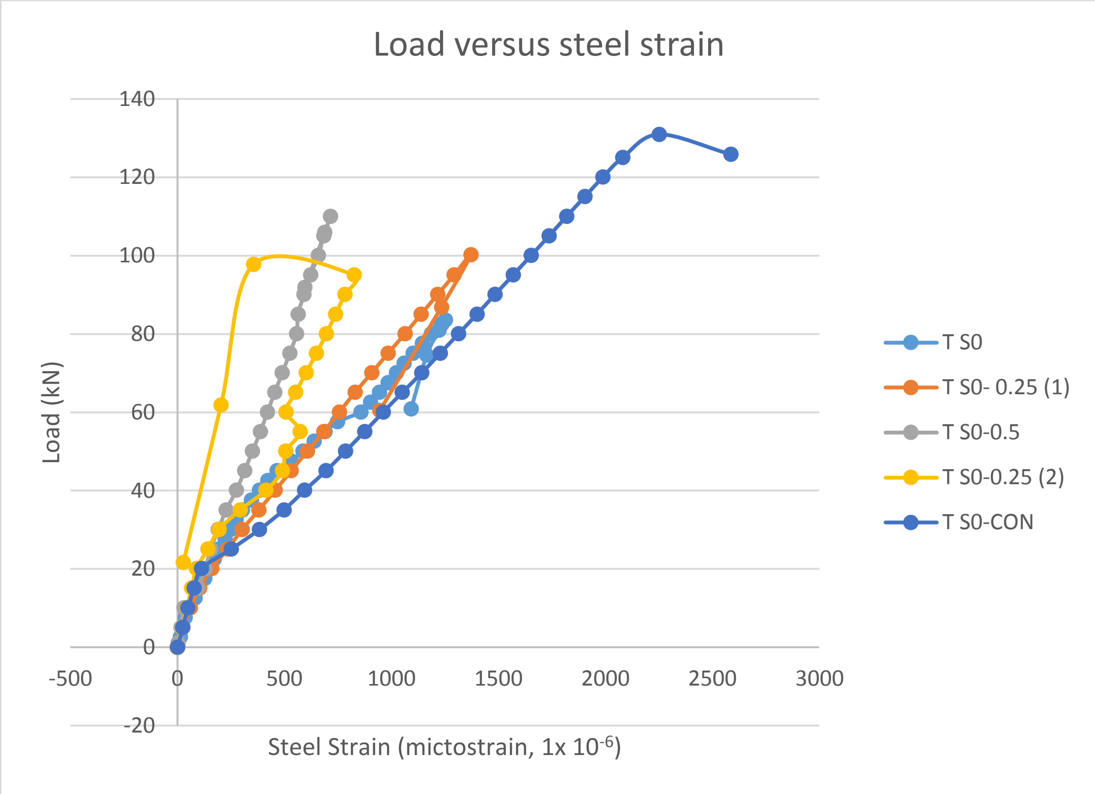

FIGURE 26. Load versus steel strain for beams without stirrups

Based on the graph, T S0-CON has higher strain as compared to other specimens. It follows in ascending order of shear reinforcement ratio. The graph starts to fall down due after reaching the ultimate failure point.

<u>With Stirrups</u>

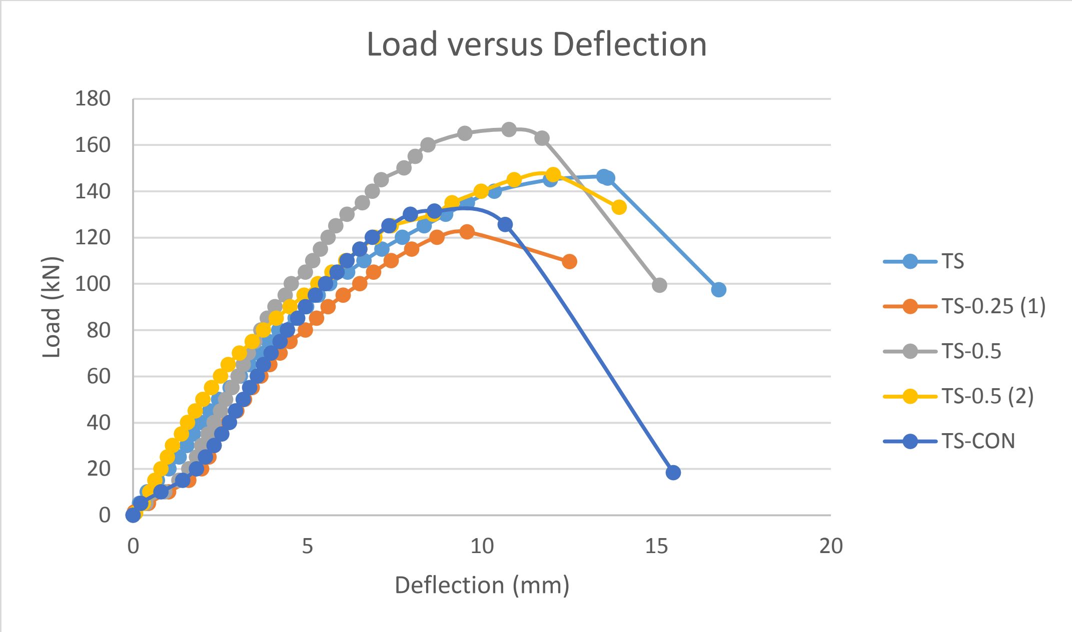

FIGURE 27. Load versus deflection for beams with stirrups

Based on this graph, it shows that T S1 has the highest load versus deflection while T S-CON and T S-0.25 (1) are among the lowest. This is because of the error during the experimental program. These two specimens had fell down during the testing. Both of the specimens supposed to be among the highest result since those beams are wrapped continuously and using large amount of FRP.

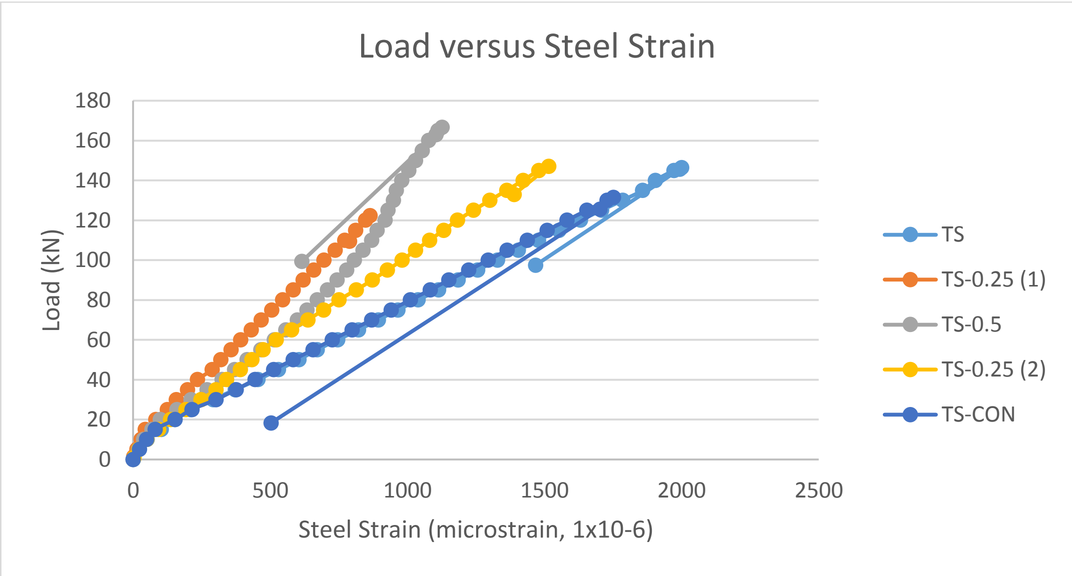

FIGURE 28. Load versus Steel Strain for beams with stirrups

Based on this graph, it shows that higher stiffness more FRP contribution. As for this graph, the comparison in order to get the conclusion needs to neglect the result from beams TS-CON and TS-0.5 (1) since there is error of the specimens. The strain of each beams different from each other because it has been determined based on the spreading and interference of the failure. All of these strain values has been taken from maximum values from the experimental data.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

This study is devoted to determine the effect of internal stirrups and externally applied Fibre-Reinforced Polymer. Besides that, the effect of shear reinforcement ratio also is can be determined. As the conclusion of this project, the presence of stirrups show better performance as compared to the specimens without stirrups. In term of shear reinforcement, continuous wrapped of FRP has better result. The more the FRP used, the better the strength. Based on calculation, the gain of continuous wrap FRP beam (TS0-CON) is 56.7 percent as compared to TS0. From this experiment it is clearly shows that the shear reinforcement is inversely proportional to the contribution of FRP. When shear reinforcement decreases, the contribution of FRP will increases. To improve the quality of the results obtained, some recommendations are outlined as follows:

a) It is recommended to make sure that the strength of concrete used is standardize for all of the specimens.
b) Besides that, the specimens should be handled carefully so that the strain gauge and the internal stirrups are in good condition during the experimental program.
c) It is worth to continue research regarding different shear reinforcement ratio and distance of stirrups in order to get better understanding.

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APPENDICES

Experimental Data

Without Stirrup

T S0

CH04	CH05	CH28
19000	19000	19000
0.09996	0.03627	1
0	0	0
kN	mm	um/m
0	0	2
2.59896	0	14
5.09796	0.07254	23
7.59696	0.18135	37
10.09596	0.3627	52
12.59496	0.50778	82
15.09396	0.61659	104
17.59296	0.76167	127
20.09196	0.83421	150
22.59096	0.90675	173
25.08996	0.97929	195
27.58896	1.0881	223
30.08796	1.16064	248
32.58696	1.26945	274
35.08596	1.37826	304
37.58496	1.52334	346
40.08396	1.63215	384
42.58296	1.70469	423
45.08196	1.8135	466
47.58096	1.88604	531
50.07996	1.99485	587
52.57896	2.06739	639
55.07796	2.13993	690
57.57696	2.24874	749
60.07596	2.32128	858
62.57496	2.43009	903
65.07396	2.50263	944
67.57296	2.61144	985
70.07196	2.68398	1023
72.57096	2.79279	1059
75.06996	2.93787	1102
77.56896	3.04668	1145
80.06796	3.19176	1186
82.56696	3.59073	1238
83.56656	3.91716	1252
82.467	4.27986	1235
80.9676	6.05709	1223
74.57016	7.18146	1165
60.87564	10.91727	1092

T S0-CON

CH04	CH05	CH28
19000	19000	19000
0.09996	0.03657	1
0	0	0
kN	Mm	um/m
0	0	1
5.09796	0.14628	25
10.09596	0.51198	49
15.09396	0.80454	78
20.09196	1.13367	113
25.08996	1.35309	252
30.08796	1.57251	384
35.08596	1.75536	498
40.08396	1.93821	595
45.08196	2.12106	695
50.07996	2.30391	786
55.07796	2.45019	875
60.07596	2.59647	962
65.07396	2.77932	1051
70.07196	2.96217	1142
75.06996	3.36444	1228
80.06796	3.58386	1314
85.06596	3.83985	1400
90.06396	4.05927	1484
95.06196	4.31526	1569
100.06	4.57125	1653
105.058	4.79067	1737
110.056	5.08323	1819
115.054	5.33922	1904
120.052	5.66835	1988
125.05	6.29004	2081
130.9476	8.88651	2251
125.8496	9.32535	2586
63.57456	14.55486	20339

T S0-0.5

CH04	CH05	CH28
19000	19000	19000
0.09996	0.03657	1
0	0	0
kN	Mm	um/m
1.19952	0.03657	4
5.09796	0.3657	17
10.09596	0.84111	31
15.09396	1.38966	94
20.09196	1.90164	130
25.08996	2.30391	156
30.08796	2.66961	191
35.08596	2.96217	228
40.08396	3.25473	276
45.08196	3.51072	314
50.07996	3.76671	351
55.07796	3.98613	388
60.07596	4.27869	421
65.07396	4.53468	455
70.07196	4.79067	490
75.06996	5.08323	525
80.06796	5.37579	557
85.06596	5.66835	564
90.06396	5.96091	592
95.06196	6.25347	622
100.06	6.61917	659
105.058	6.98487	684
110.056	7.53342	715
105.9576	8.0454	689
91.86324	10.64187	596

T S0-0.25 (2)

CH04	CH05	CH28
19000	19000	19000
0.09996	0.03657	1
0	0	0
kN	Mm	um/m
0	0	-1
5.09796	0.3657	26
10.09596	0.76797	60
15.09396	1.13367	104
20.09196	1.4628	160
25.08996	1.8285	234
30.08796	2.08449	303
35.08596	2.34048	381
40.08396	2.63304	457
45.08196	2.85246	532
50.07996	3.07188	607
55.07796	3.2913	684
60.07596	3.51072	757
65.07396	3.76671	830
70.07196	4.0227	908
75.06996	4.24212	984
80.06796	4.53468	1064
85.06596	4.79067	1139
90.06396	5.15637	1216
95.06196	5.66835	1293
100.2599	6.80202	1372
86.86524	7.89912	1234
60.4758	12.72636	946

T S0-0.25 (1)

CH04	CH05	CH28
19000	19000	19000
0.09996	0.03657	1
0	0	0
kN	mm	um/m
-0.09996	0	0
5.09796	0.29256	22
10.09596	0.84111	45
15.09396	1.49937	67
20.09196	1.93821	89
25.08996	2.23077	143
30.08796	2.48676	195
35.08596	2.77932	294
40.08396	2.99874	414
45.08196	3.25473	491
50.07996	3.51072	506
55.07796	3.76671	573
60.07596	3.98613	508
65.07396	4.16898	553
70.07196	4.46154	601
75.06996	4.79067	650
80.06796	5.1198	696
85.06596	5.70492	739
90.06396	6.36318	782
95.06196	7.09458	826
97.76088	723.9763	356
61.87524	723.9763	204
21.69132	723.9763	28

With stirrups

TS

CH04	CH05	CH28
19000	19000	19000
0.09996	0.03657	1
0	0	0
kN	Mm	um/m
0	0	1
5.09796	0.18285	22
10.09596	0.40227	51
15.09396	0.69483	102
20.09196	1.02396	152
25.08996	1.31652	208
30.08796	1.53594	291
35.08596	1.71879	372
40.08396	1.93821	455
45.08196	2.1942	530
50.07996	2.45019	604
55.07796	2.77932	671
60.07596	3.07188	746
65.07396	3.32787	822
70.07196	3.58386	894
75.06996	3.87642	965
80.06796	4.16898	1039
85.06596	4.64439	1114
90.06396	4.97352	1185
95.06196	5.30265	1256
100.06	5.63178	1329
105.058	6.14376	1405
110.056	6.61917	1478
115.054	7.13115	1553
120.052	7.71627	1631
125.05	8.33796	1708
130.048	8.95965	1785
135.046	9.58134	1858
140.044	10.34931	1904
145.042	11.95839	1972
146.4414	13.49433	2000
145.6417	13.60404	1993
97.461	16.78563	1467

TS-CON

CH04	CH06	CH28
19000	19000	19000
0.09996	0.03627	1
0	0	0
kN	mm	um/m
0	0	0
5.09796	0.21762	23
10.09596	0.79794	49
15.09396	1.41453	80
20.09196	1.8135	153
25.08996	2.06739	214
30.08796	2.32128	302
35.08596	2.5389	375
40.08396	2.75652	444
45.08196	2.93787	512
50.07996	3.15549	583
55.07796	3.33684	656
60.07596	3.55446	726
65.07396	3.73581	798
70.07196	3.95343	870
75.06996	4.20732	941
80.06796	4.42494	1011
85.06596	4.7151	1083
90.06396	4.93272	1151
95.06196	5.22288	1224
100.06	5.51304	1295
105.058	5.83947	1364
110.056	6.12963	1437
115.054	6.49233	1510
120.052	6.85503	1582
125.05	7.32654	1655
130.048	7.94313	1728
131.4474	8.63226	1751
125.6497	10.66338	1702
18.39264	15.48729	503

TS-0.5

CH04	CH06	CH28
19000	19000	19000
0.09996	0.03627	1
0	0	0
kN	mm	um/m
0	0	0
5.09796	0.3627	19
10.09596	0.90675	38
15.09396	1.30572	68
20.09196	1.59588	99
25.08996	1.8135	160
30.08796	1.95858	211
35.08596	2.13993	269
40.08396	2.32128	324
45.08196	2.50263	370
50.07996	2.64771	415
55.07796	2.82906	466
60.07596	3.01041	514
65.07396	3.15549	557
70.07196	3.30057	599
75.06996	3.48192	634
80.06796	3.66327	671
85.06596	3.84462	708
90.06396	4.06224	744
95.06196	4.3524	779
100.06	4.53375	807
105.058	4.93272	838
110.056	5.15034	870
115.054	5.36796	890
120.052	5.58558	919
125.05	5.8032	929
130.048	6.12963	949
135.046	6.56487	960
140.044	6.85503	979
145.042	7.10892	1005
150.04	7.76178	1029
155.038	8.08821	1054
160.036	8.45091	1078
165.034	9.50274	1111
166.6333	10.77219	1127
162.9348	11.71521	1104
99.36024	15.08832	615

TS-0.25 (2)

CH04	CH05	CH28
19000	19000	19000
0.09996	0.03627	1
0	0	0
kN	mm	um/m
1.39944	0.03627	2
5.09796	0.43524	13
10.09596	1.01556	29
15.09396	1.59588	44
20.09196	1.95858	82
25.08996	2.1762	125
30.08796	2.32128	157
35.08596	2.50263	198
40.08396	2.72025	234
45.08196	2.97414	288
50.07996	3.19176	320
55.07796	3.40938	357
60.07596	3.66327	392
65.07396	3.91716	430
70.07196	4.20732	467
75.06996	4.49748	505
80.06796	4.93272	545
85.06596	5.25915	583
90.06396	5.58558	620
95.06196	6.02082	658
100.06	6.49233	696
105.058	6.8913	736
110.056	7.39908	772
115.054	7.9794	811
120.1519	8.7048	847
122.451	9.57528	864
109.5562	12.51315	789

TS-0.25 (1)

CH04	CH05	CH28
19000	19000	19000
0.09996	0.03627	1
0	0	0
kN	mm	um/m
0.89964	0.07254	3
5.09796	0.29016	20
10.09596	0.47151	50
15.09396	0.61659	93
20.09196	0.79794	136
25.08996	0.97929	192
30.08796	1.12437	247
35.08596	1.37826	302
40.08396	1.55961	341
45.08196	1.77723	391
50.07996	1.99485	433
55.07796	2.24874	474
60.07596	2.50263	521
65.07396	2.72025	578
70.07196	3.04668	637
75.06996	3.40938	694
80.06796	3.73581	750
85.06596	4.09851	813
90.06396	4.49748	872
95.06196	4.89645	927
100.06	5.29542	981
105.058	5.69439	1030
110.056	6.09336	1081
115.054	6.49233	1132
120.052	6.92757	1183
125.05	7.39908	1241
130.048	8.59599	1301
135.046	9.14004	1362
140.044	9.97425	1422
145.042	10.91727	1479
147.1411	12.04164	1515
133.0468	13.92768	1389